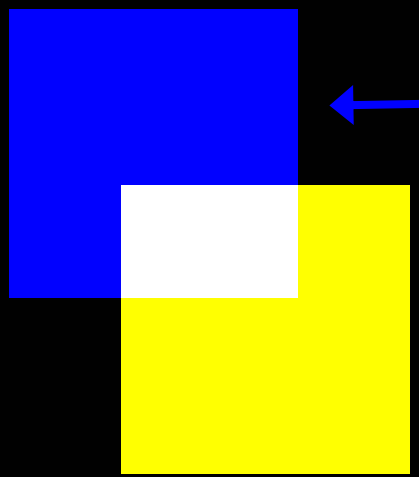
Complexities of Color

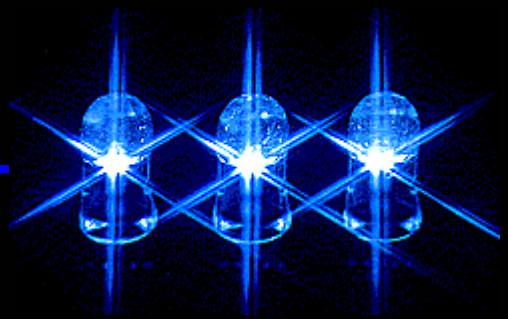
Wendy Davis, Ph.D.

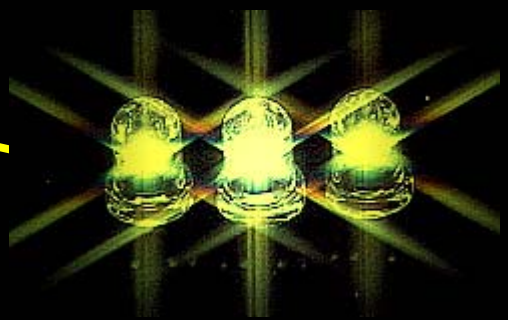
Optical Technology Division
National Institute of Standards and Technology

All Whites Are Not Created Equal

Blue + Yellow = White







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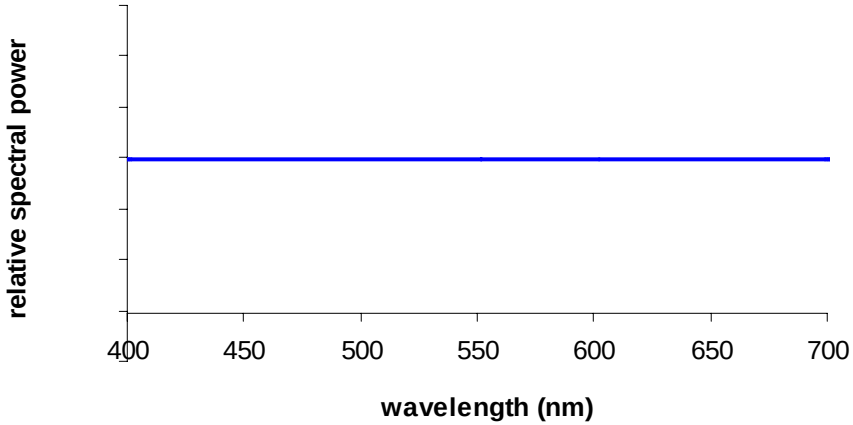
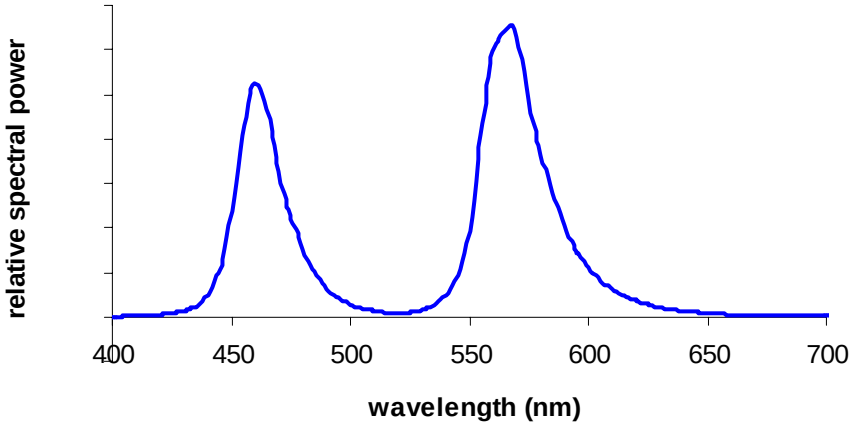
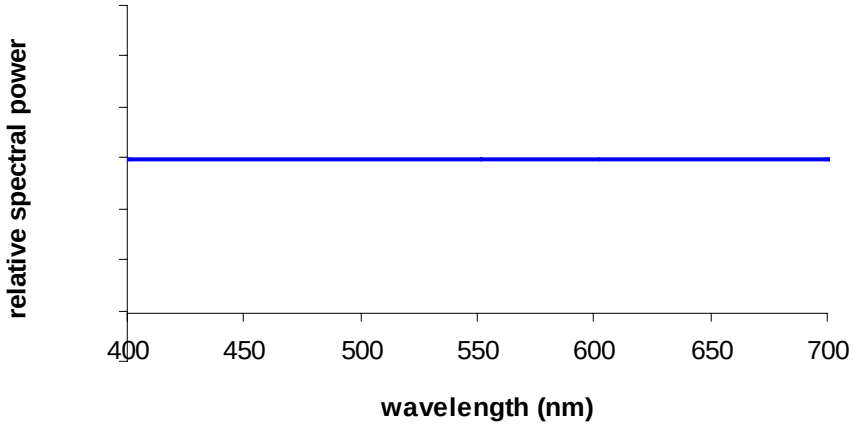
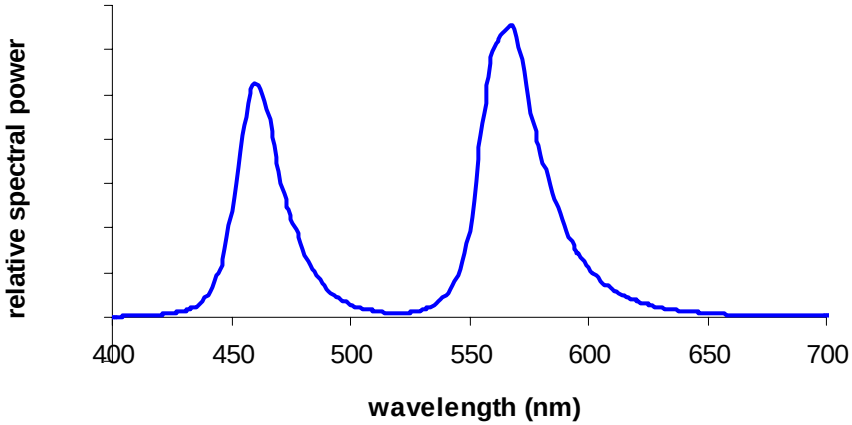
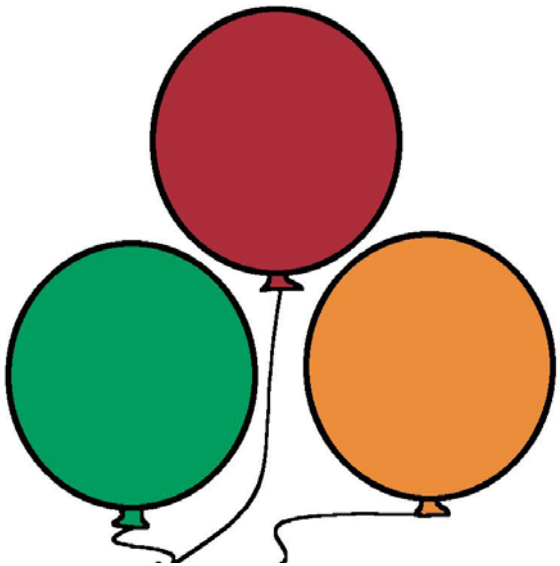


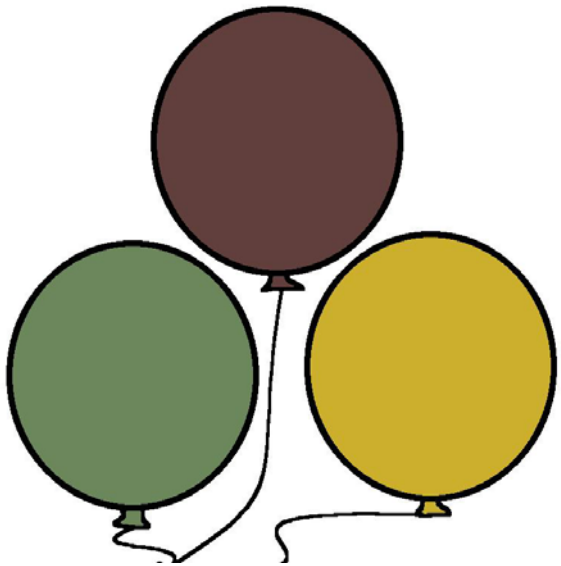


All Whites Are Not Created Equal









Overview of Talk

Differences across the population: two examples

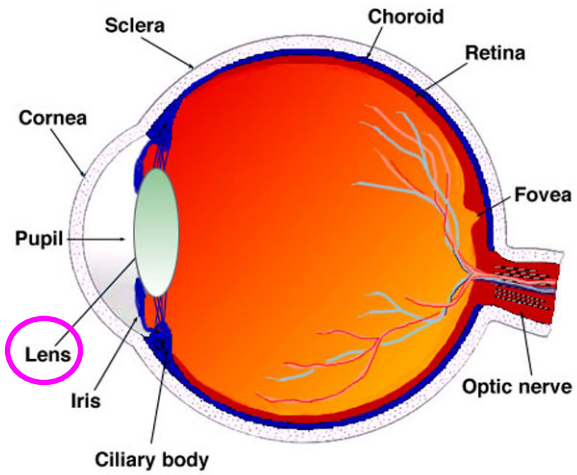
Situational variables

How can SSL developers assess color rendering quality?

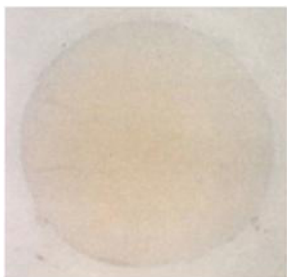
- Color rendering Index (CRI)
- Some pretty serious problems
- Updating reflective samples

Differences Across the Population

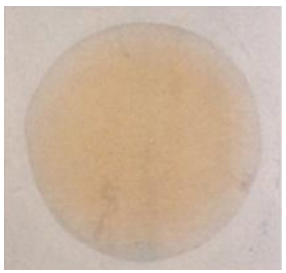
The lens of the eye yellows with age



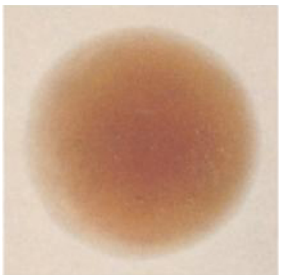
25 years



60 years



82 years



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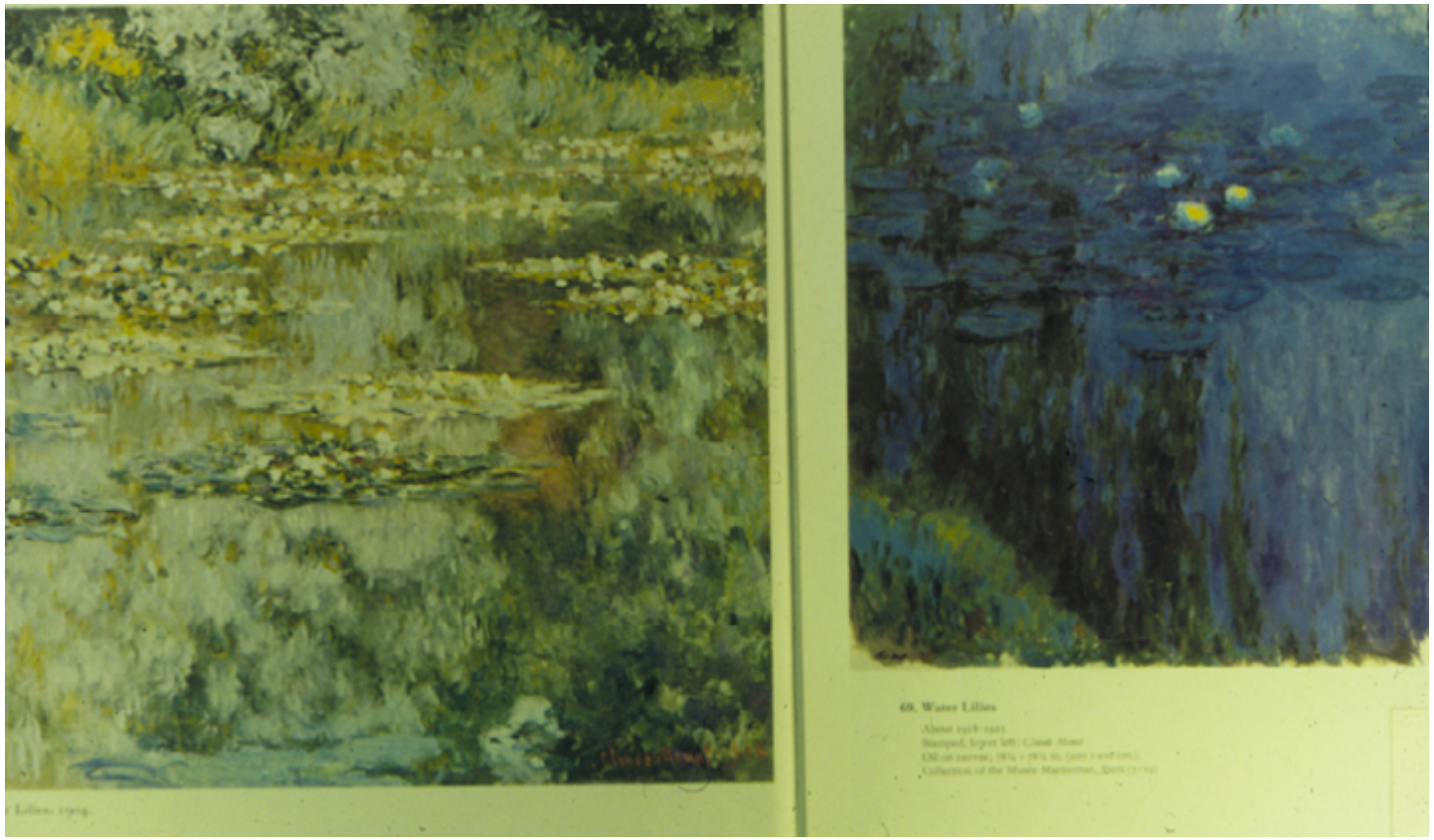
*From Lerman, 1980

Differences Across the Population

http://www.sequimvision.com/eyehealt.htm

http://www.richmondeye.com/simulation.htm

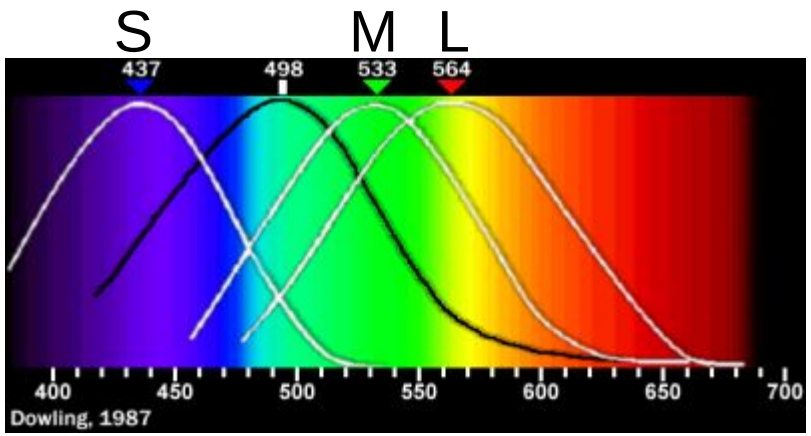
Differences Across the Population



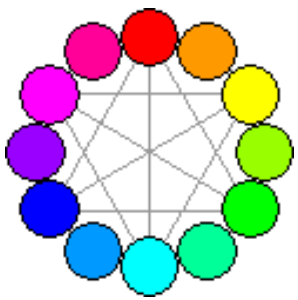
Monet's water lilies at Giverny painted before (left) and after (right) his cataract surgery

Differences Across the Population

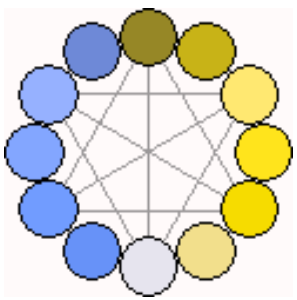
8% of males have shifted or missing L or M cone photopigments



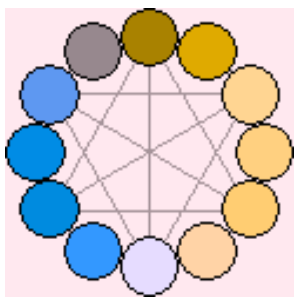
Normal



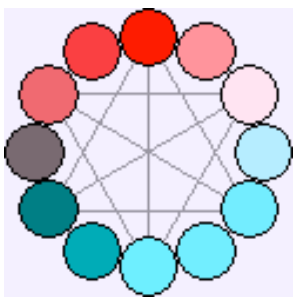
Protanopic



Deuteranopic



Tritanopic

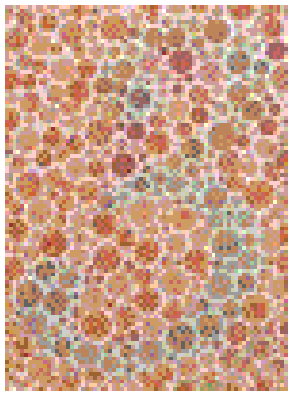


Images from http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dnhess/html/hess10092000.asp

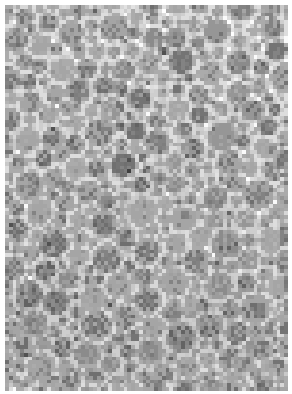
Differences Across the Population

Clinical tests of color vision use knowledge of differential cone activation

People with normal color vision perceive a “3”



People with abnormal color vision perceive a “5”



People with no color vision perceive only grey

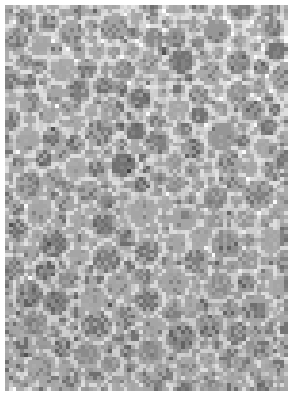
Images from http://www.richmondeye.com/simulation.htm

Differences Across the Population

Clinical tests of color vision use knowledge of differential cone activation

People with normal color vision perceive a “3”

People with abnormal color vision perceive a “5”

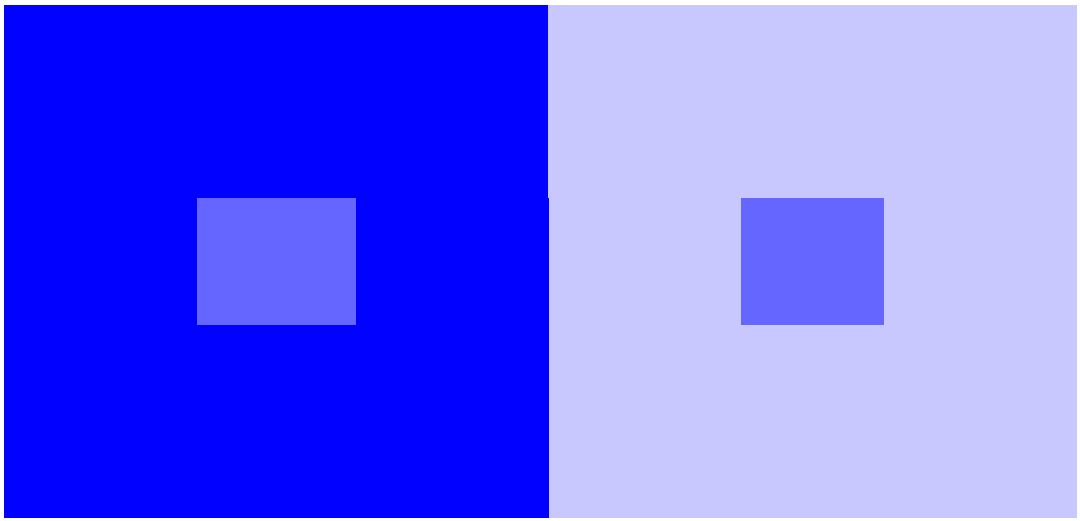


People with no color vision perceive only grey

Images from http://www.richmondeye.com/simulation.htm

Situational Variables

Spatial Context: Chromatic Saturation

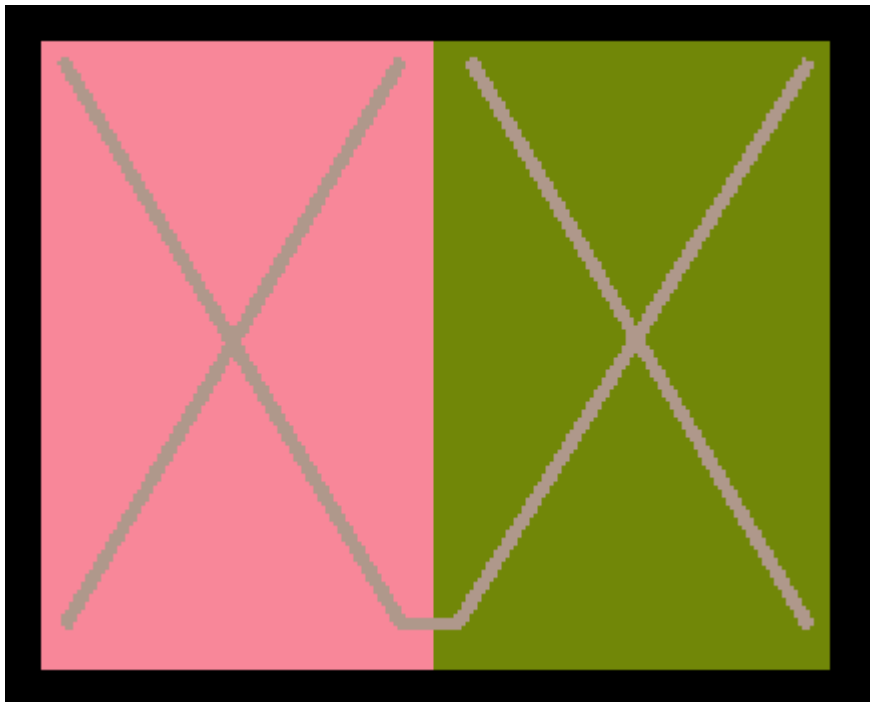


Situational Variables

Spatial Context: Chromatic Saturation

Situational Variables

Spatial Context: Hue



http://acc4.its.brooklyn.cuny.edu/~lscarlat/GUI/simulcontrast.htm

Situational Variables

Spatial Context: Hue

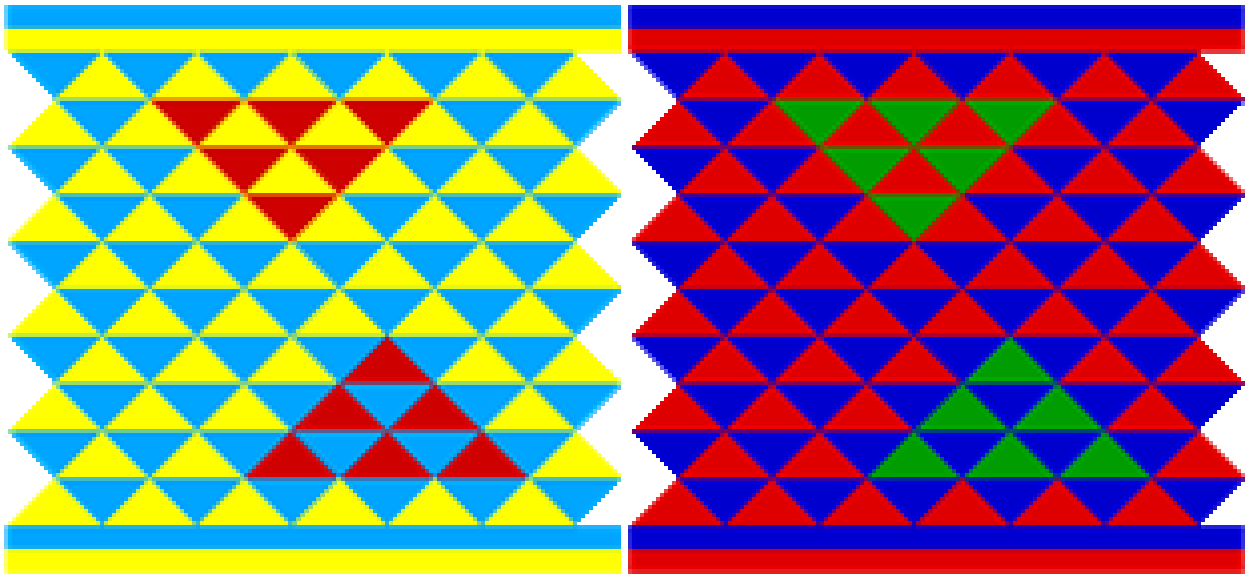


Image from http://www.colorcube.com/illusions/scstripe.htm

Situational Variables

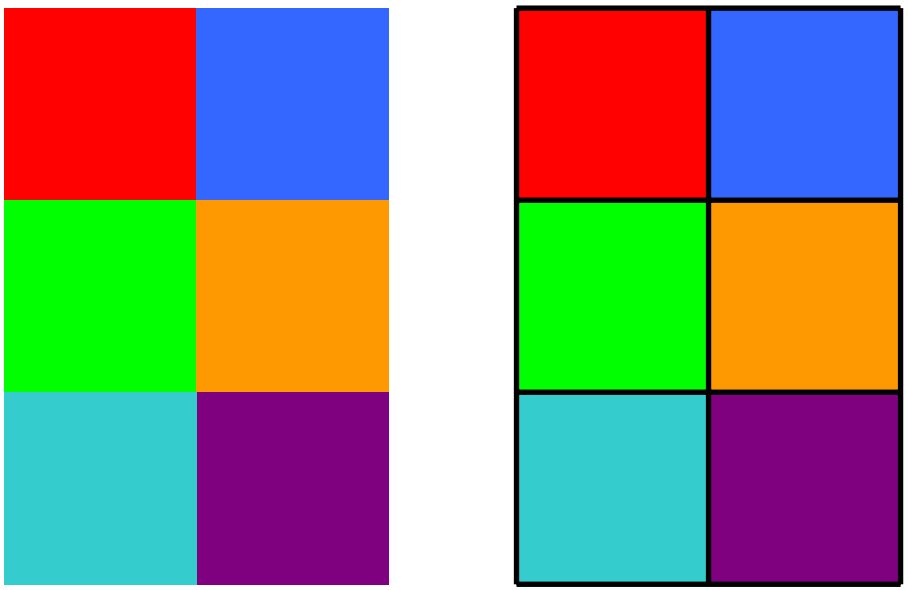
Spatial Context: Hue

Image from http://cs.haifa.ac.il/hagit/courses/ist/Lectures/IST05_ColorLABx4.pdf

Illusion by Monnier & Shevell, 2003

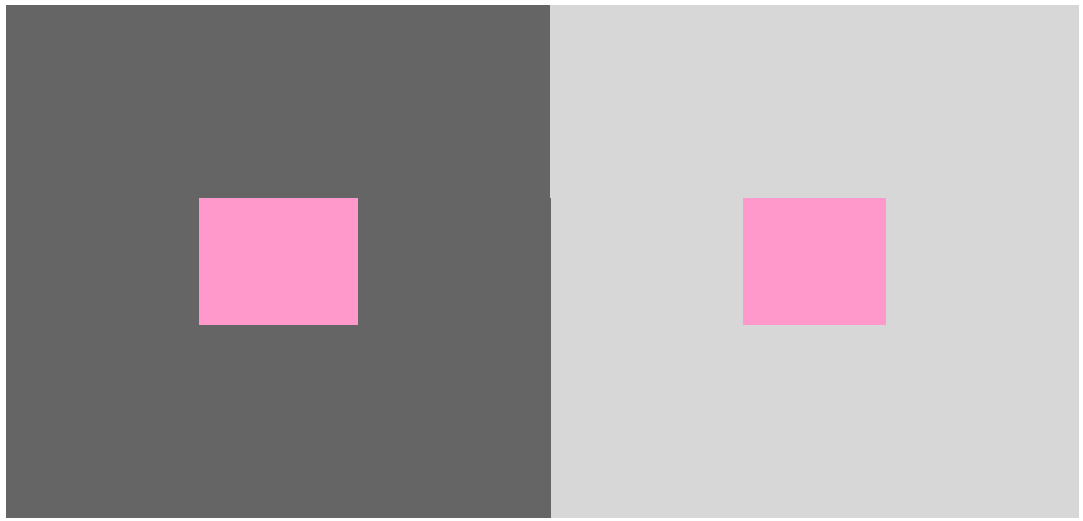
Situational Variables

Spatial Context: Luminance



Situational Variables

Spatial Context: Luminance



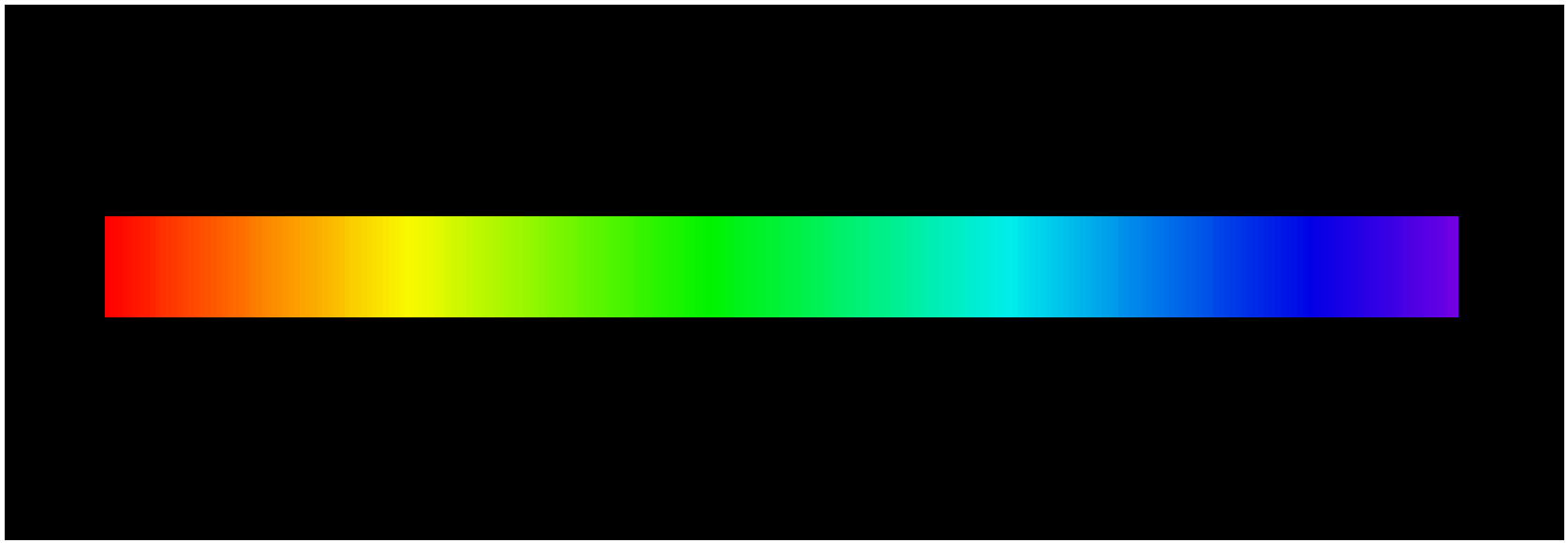
Situational Variables

Spatial Context: Luminance

Situational Variables

Spatial Characteristics: Luminance

Bezold-Brücke Effect



Demo from http://www.psych.ucsb.edu/~rowe/Bezold-Brucke.html

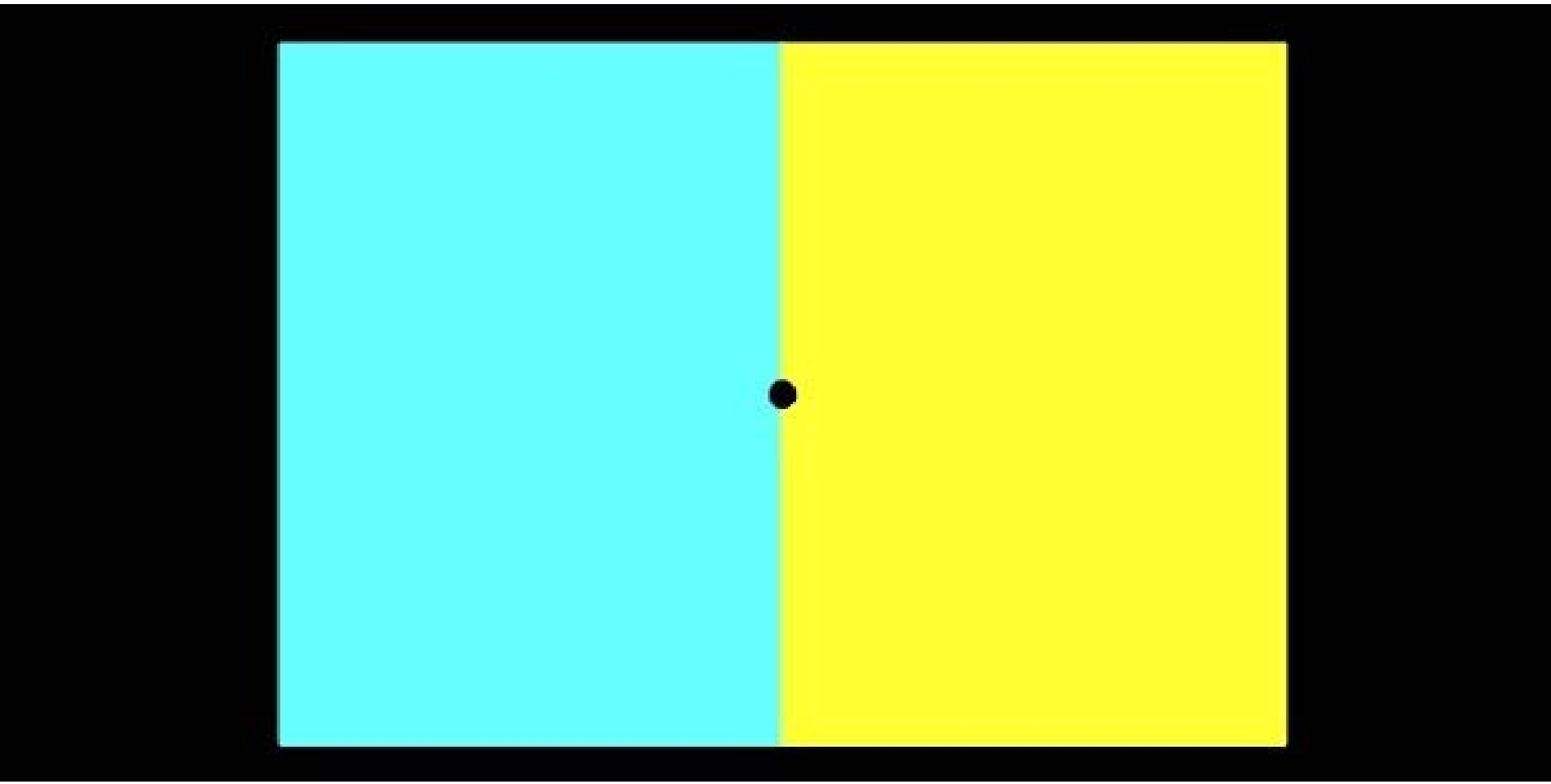
Situational Variables

Chromatic Adaptation

Images from http://www.colorcube.com/illusions/chrmadpt.htm

Situational Variables

Chromatic Adaptation



Images from http://www.colorcube.com/illusions/chrmadpt.htm

Situational Variables

Chromatic Adaptation

Images from http://www.colorcube.com/illusions/chrmadpt.htm

Situational Variables

Chromatic Afterimages

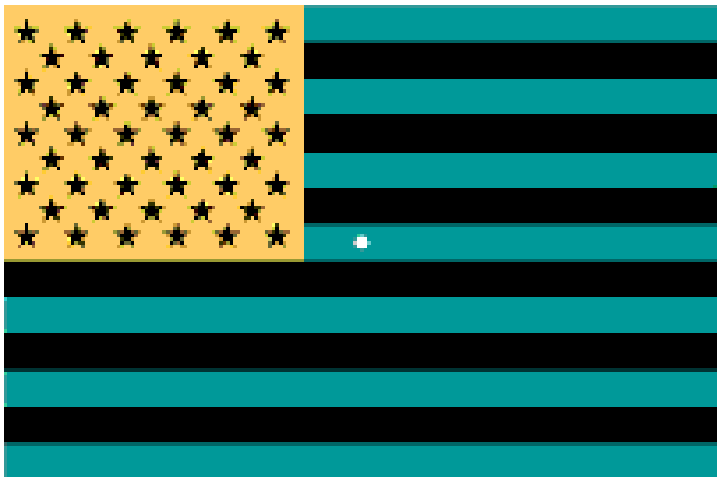


Image from http://www.cybersisman.com/psych1a/unit6/unit6notes.html

Situational Variables

Chromatic Afterimages

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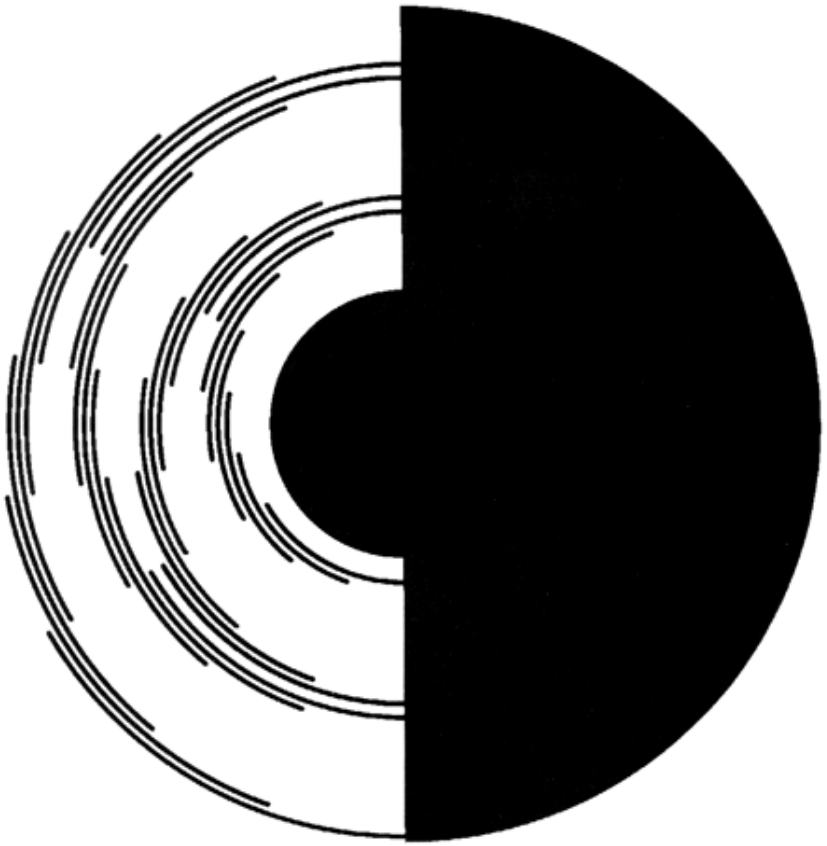
Image from http://www.cybersisman.com/psych1a/unit6/unit6notes.html

Situational Variables

Motion

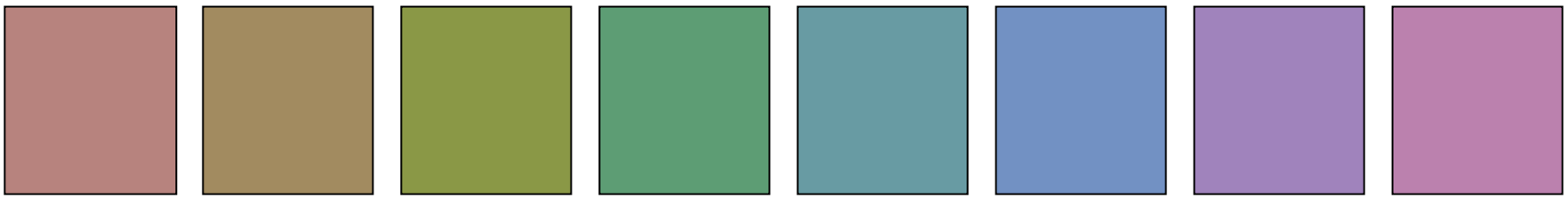


Stationary image from http://www.exploratorium.edu/snacks/benhams_disc_graph.html

How Can SSL Developers Assess Color Rendering Quality?

Color Rendering Index (CRI)

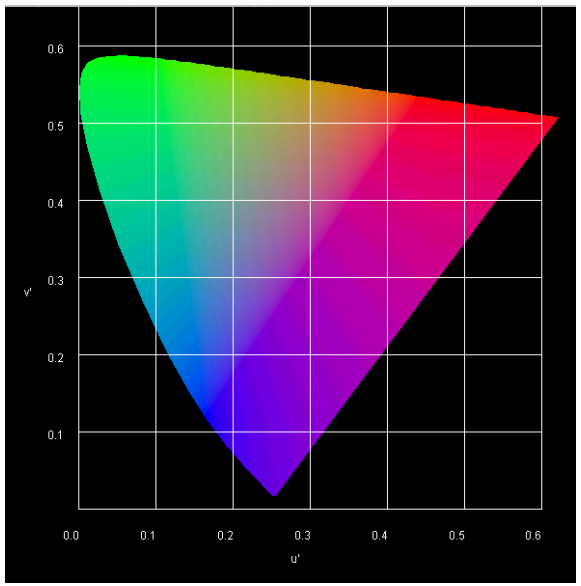
Quantifies difference in color appearance of eight samples when illuminated by a given source and blackbody source of same CCT



CIE 13.3

Color Rendering Index (CRI)

Differences in color appearance are differences in 1964 *W*U*V** uniform color space (now obsolete)



Color Rendering Index (CRI)

<u>Some pretty serious problems</u>

Outdated color space and chromatic adaptation correction formula

Effect of color temperature is negated

Few reflective samples; all low-moderate saturation

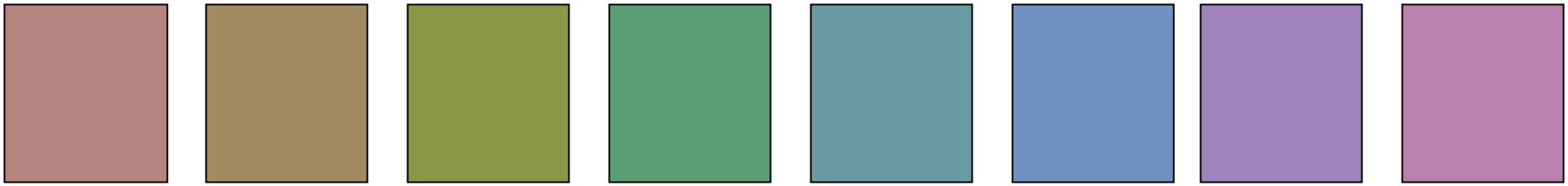
Improving the CRI

Wendy Davis and Yoshi Ohno

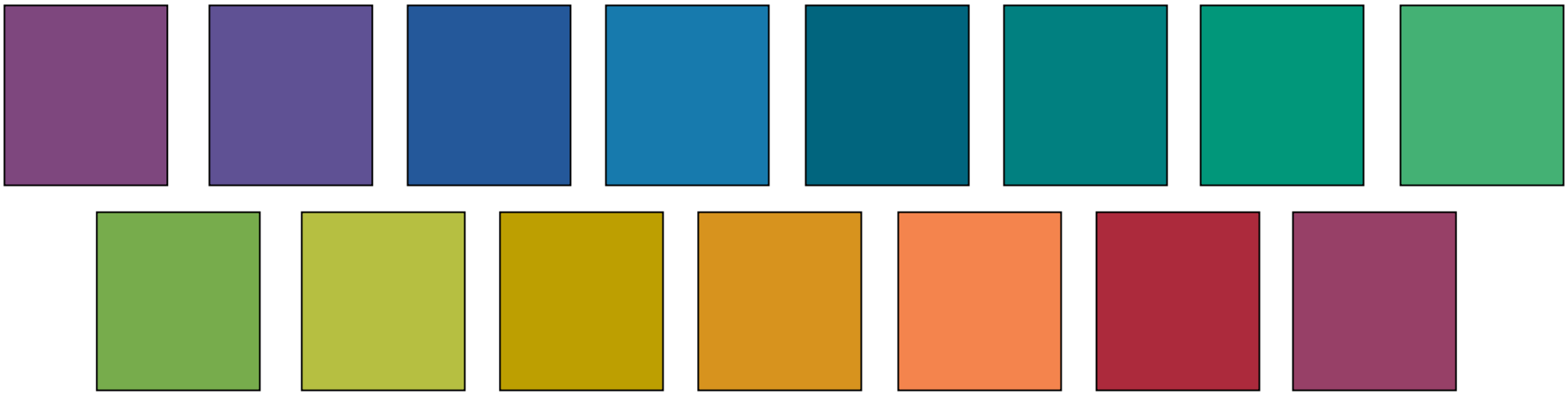
Optical Technology Division
National Institute of Standards and Technology

Updating the Reflective Samples

Eight old samples:



15 proposed new samples:



Updating the Reflective Samples

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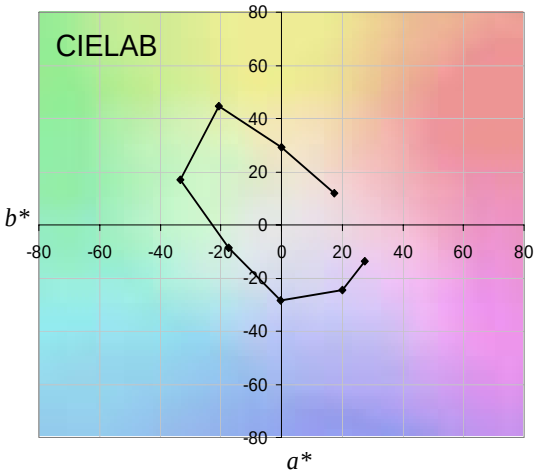

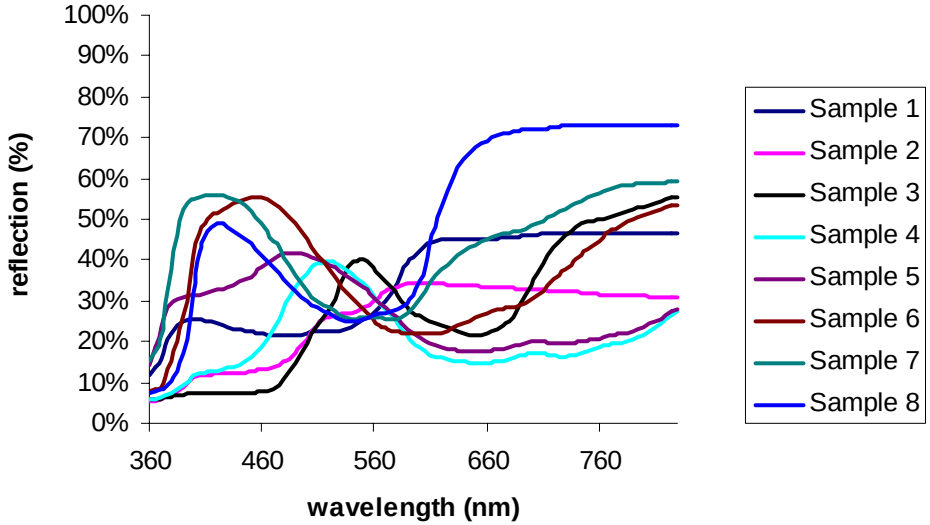

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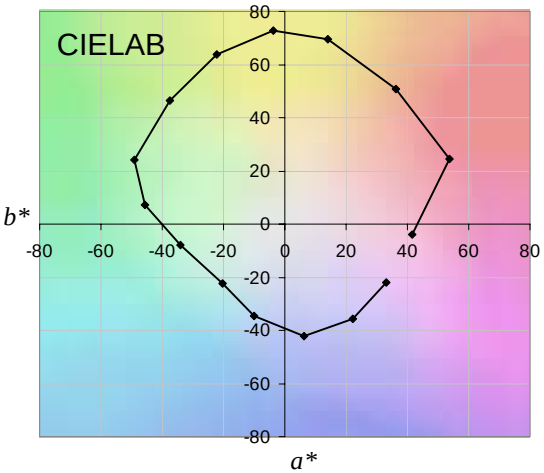
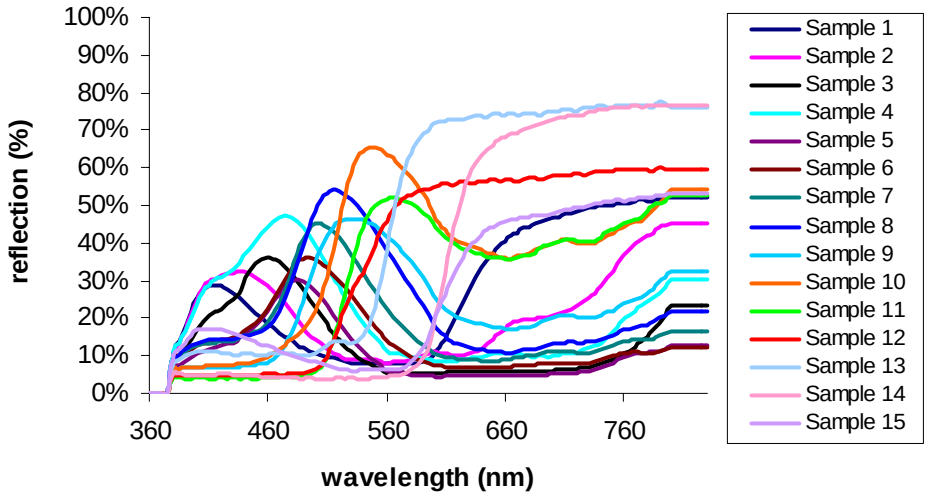


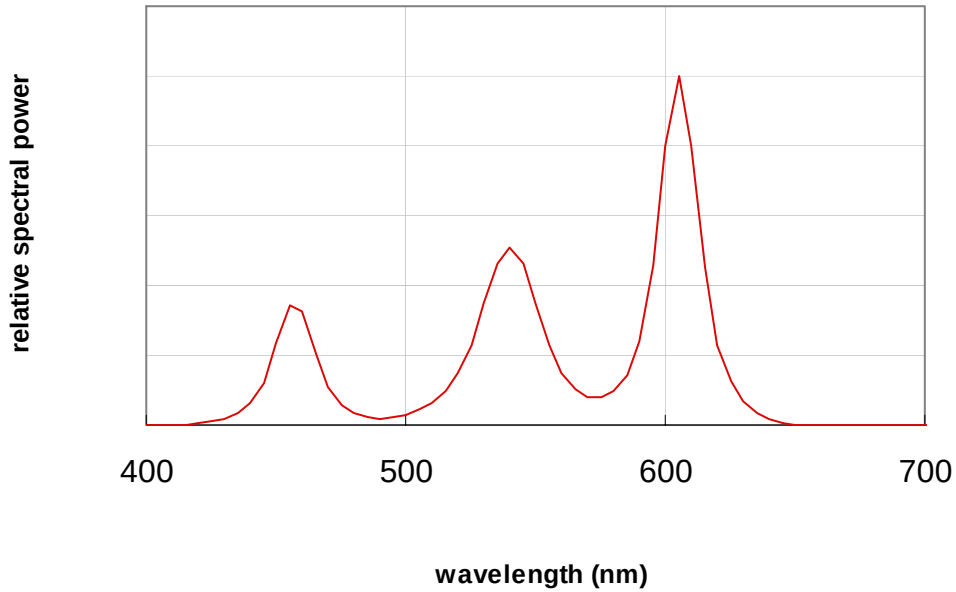


Updating the Reflective Samples

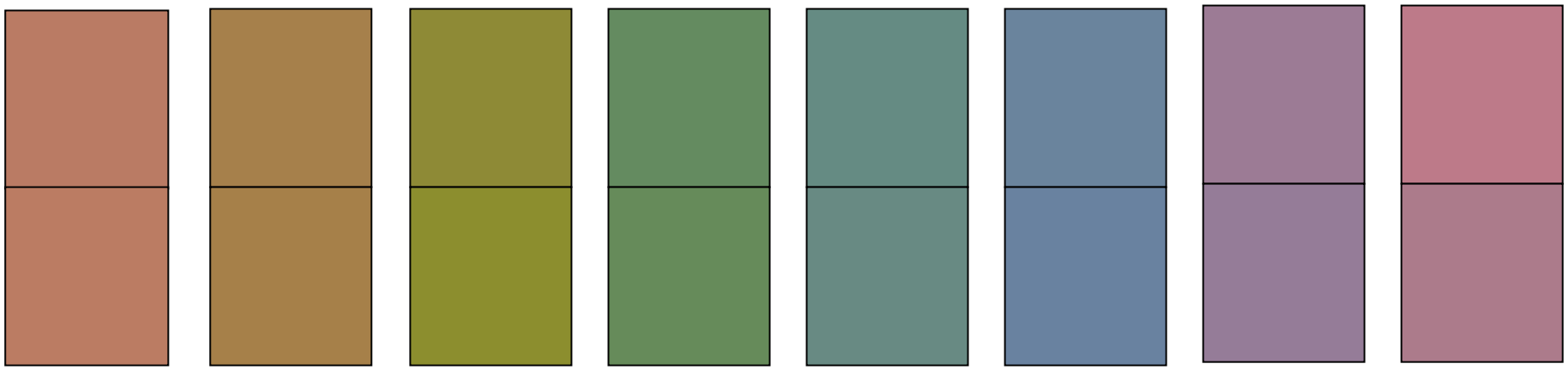
3-LED Model

Peaks at:

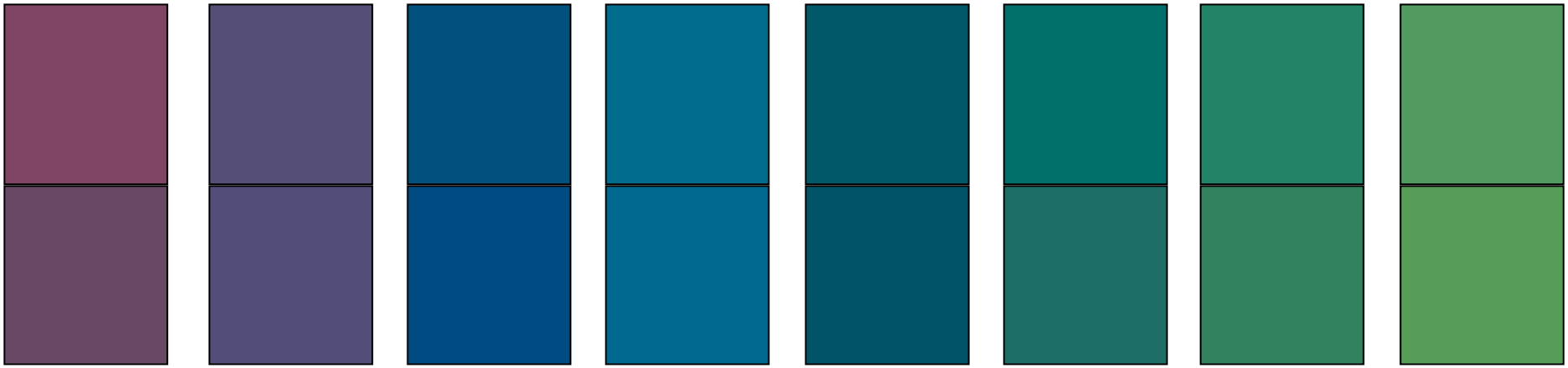
457, 540, & 605 nm



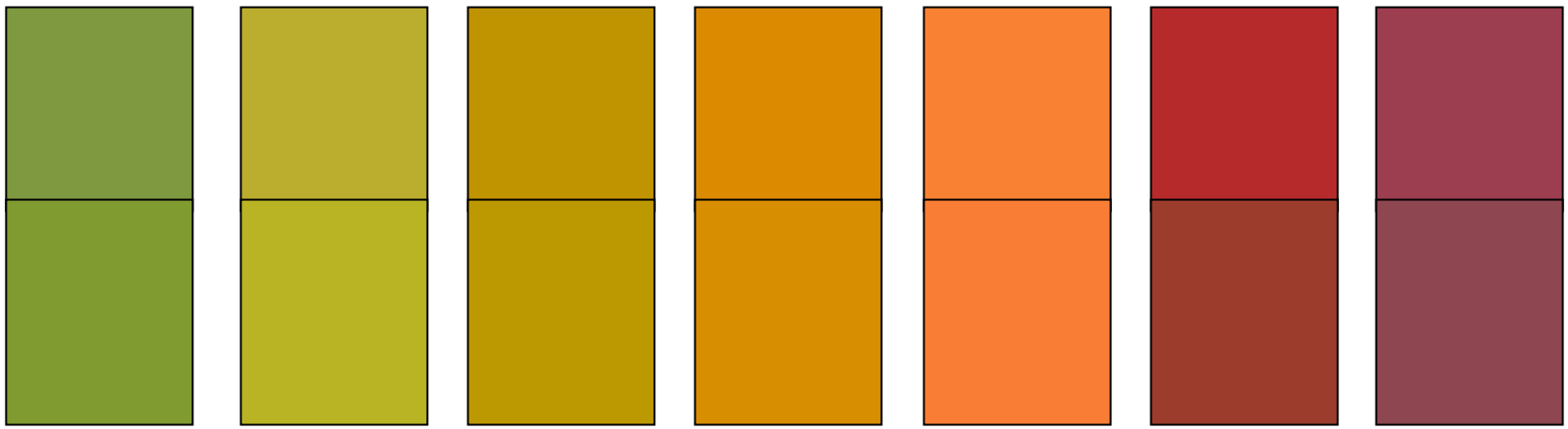
$R_a = 80$



Updating the Reflective Samples



$R_{newsamples} = 56$

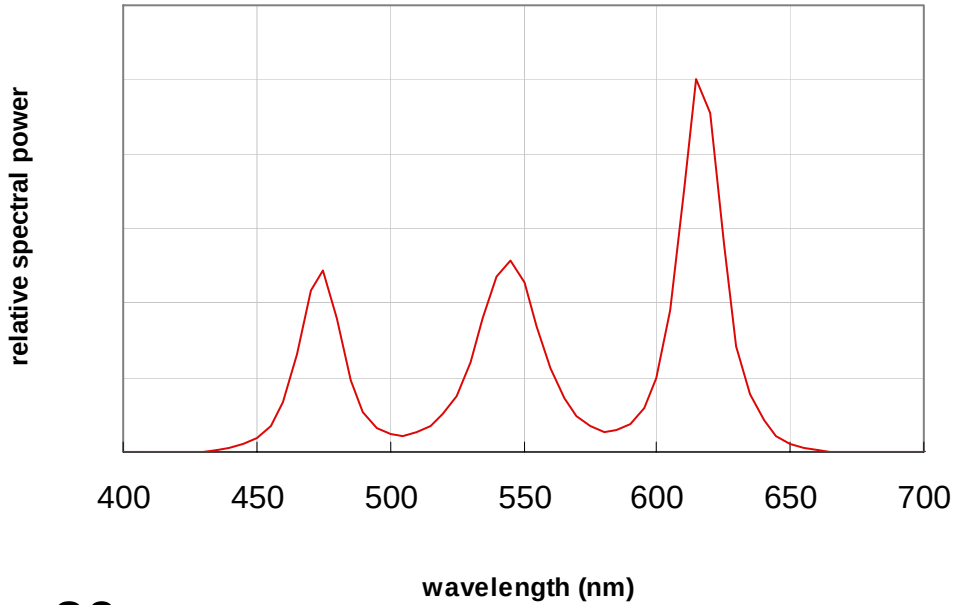


Updating the Reflective Samples

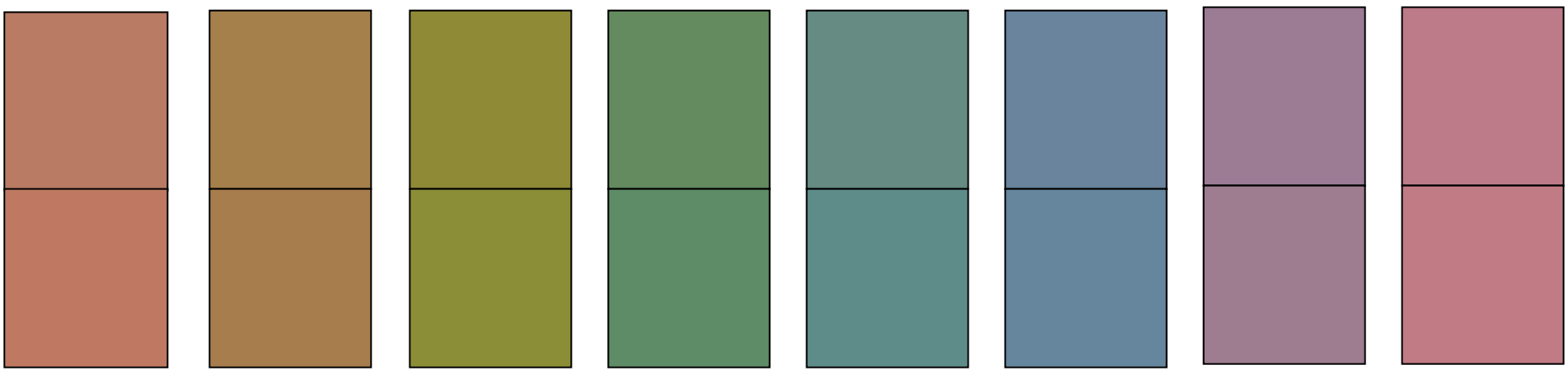
3-LED Model

Peaks at:

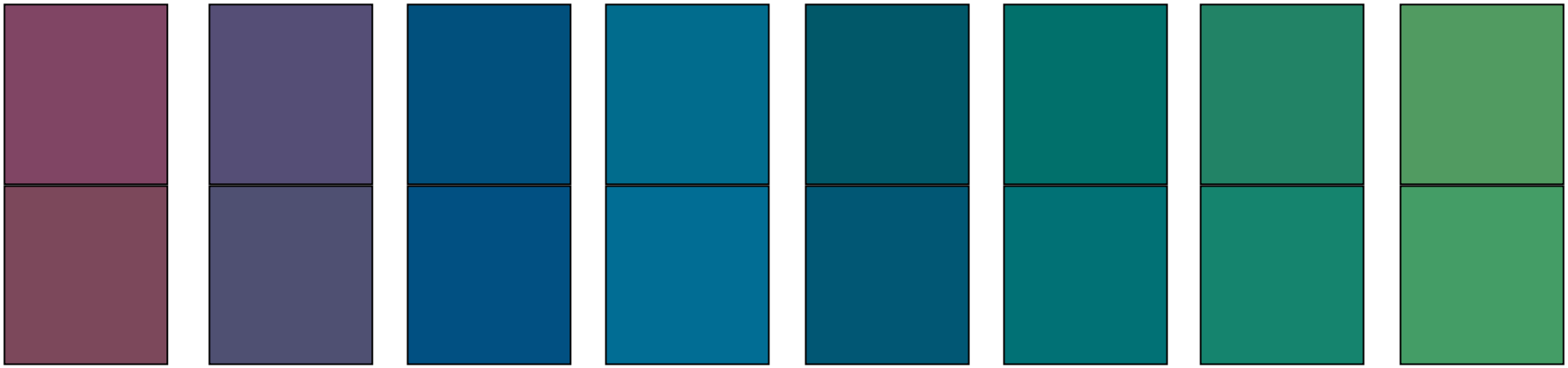
473, 545, & 616 nm



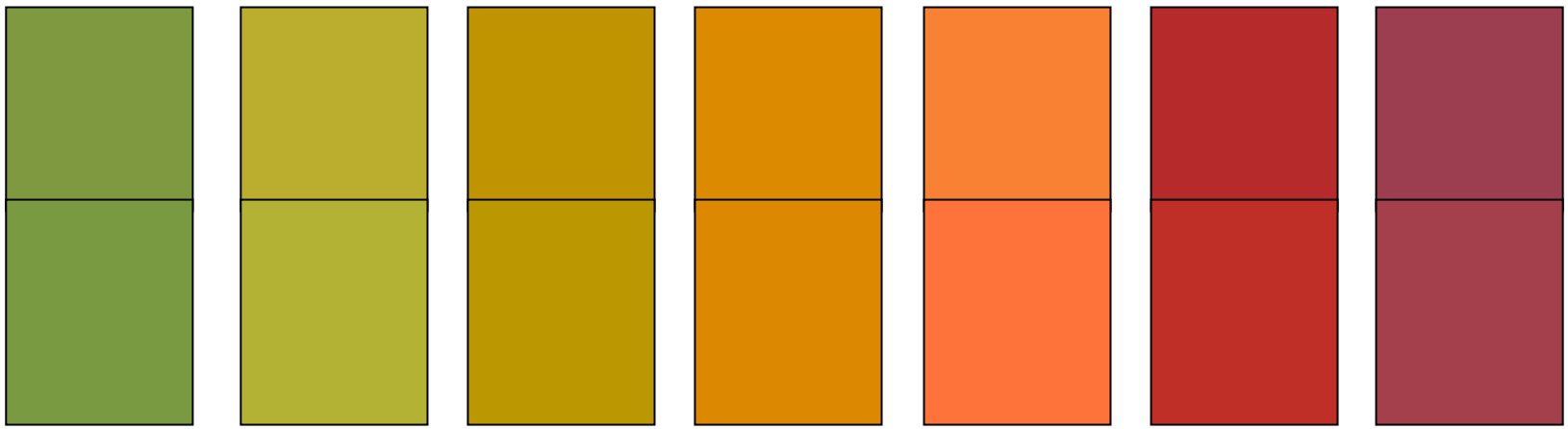
$R_a = 80$



Updating the Reflective Samples



$R_{newsamples} = 72$



Updating the Reflective Samples

<u>More work underway</u>

Use updated color space (CIELAB)

Use updated chromatic adaptation correction formula (probably Bradford transform)

Calculate differences so that increases in saturation (chroma) do not lower scores

Address use of referents matched in CCT

For Additional Information

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Yoshi Ohno: ohno@nist.gov